PATENT COOPERATION TREATY



# PCT

## INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

| Applicant's or agent's file reference G69335/MP/sgh | FOR FURTHER ACTION | See Form PCT/IPEA/416 |
|---|---|---|
| International application No. PCT/IB2004/001197 | International filing date *(day/month/year)* 21.04.2004 | Priority date *(day/month/year)* 23.04.2003 |
| International Patent Classification (IPC) or national classification and IPC H01S3/109, H01S3/042 | | |
| Applicant BRIGHT SOLUTIONS - SOLUZIONI LASER... et al. | | |

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 5 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of eight sheets, as follows:
      ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.
   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

| | | |
|---|---|---|
| ☒ | Box No. I | Basis of the opinion |
| ☐ | Box No. II | Priority |
| ☐ | Box No. III | Non-establishment of opinion with regard to novelty, inventive step and industrial applicability |
| ☐ | Box No. IV | Lack of unity of invention |
| ☒ | Box No. V | Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement |
| ☐ | Box No. VI | Certain documents cited |
| ☐ | Box No. VII | Certain defects in the international application |
| ☐ | Box No. VIII | Certain observations on the international application |

| Date of submission of the demand | Date of completion of this report |
|---|---|
| 18.02.2005 | 11.07.2005 |
| Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465 | Authorized Officer Gnugesser, H Telephone No. +49 89 2399-2526 |

# INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/IB2004/001197

## Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

**Description, Pages**

| | |
|---|---|
| 1-6, 8, 10-12, 14-27 | as originally filed |
| 7, 9, 13 | received on 21.02.2005 with letter of 17.02.2005 |

**Claims, Numbers**

| | |
|---|---|
| 1-22 | received on 21.02.2005 with letter of 17.02.2005 |

**Drawings, Sheets**

| | |
|---|---|
| 1/3-3/3 | as originally filed |

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

**Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

| | | | |
|---|---|---|---|
| Novelty (N) | Yes: | Claims | 1-22 |
| | No: | Claims | |
| Inventive step (IS) | Yes: | Claims | 1-22 |
| | No: | Claims | |
| Industrial applicability (IA) | Yes: | Claims | 1-22 |
| | No: | Claims | |

2. Citations and explanations (Rule 70.7):

**see separate sheet**

**Re Item V**

**Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

Reference is made to the following documents:

D1: US 6 287 298 B

From D1 (see: fig. 3 and description col. 5, line 22 - col. 6, line 60; col. 10, lines 1 - 35) the technical features defined in the preamble of claim 1. In the device of D1 type I non critical phase matching is used.

The subject-matter of claim 1 is therefrom distinguished in that

- the non-linear crystal is able to generate a second harmonic of said fundamental wavelength by **critica**l type I phase matching;
- the cavity is associated to thermostating means for temperature locking said cavity and its optical elements.

These distinguishing technical features solve the following problem: design of a simple and compact laser structure for the generation of high power visible laser beams with high spatial quality.

The above distinguishing technical features are neither known nor indicated by the available prior art in order to solve the problem posed. The **critical phase matching** of claim 1 allows room temperature to be chosen for all fundamental wavelengths whereas the non-critical phase matching of the device of D1 works at a temperature of the crystal which is different for each fundamental wavelength. There is no reason for the person skilled in the art to change the configuration of the device of D1 in a way to arrive at the subject-matter of claim 1. Although made from the same crystal lattice it is to be noted that the same non-critical phase matching crystal cannot be used for critical phase matching. It is further to be noted that the above distinguishing technical features can not be considered as an obvious measure well known to the person skilled in the art. Consequently, there is no reason to develop the subject-matter of claim 1 from the available prior art without exercise of inventive step.

Claim 20 defines a method for generating a visible laser beam in an apparatus according to claim 1. Therefore, the subject-matter of claim 20 is also novel and involves an inventive step.

Claims 2 - 19 and 21, 22 are dependent claims which directly or indirectly refer back to claims 1 and 20 respectively. These claims are therefore novel and involve an inventive step.

thermostating means which allow to minimise infrared losses and maximum the optical efficiency of the system operating the ICSHG, whilst entailing the desired flexibility in the generation of different wavelength, and the compactness, simplicity, robustness and energy efficiency of the laser head.

Figure 1 shows a schematic diagram of a laser apparatus 71 according to the invention.

Said device 71 substantially comprises a laser cavity 72, on which impinges a pumping beam 54 generated by an external source 73.

In said laser cavity 72 or resonator the pumping beam 54 initially meets a pumping mirror 30 provided with a face 32, transparent to pumping, and with a face 31 reflecting towards the interior of the cavity 72, then meets a first face 11 of an active crystal 10. In the active crystal 10 the pumping beam 54 generates a laser beam 52 at fundamental wavelength which projects from a second face 12 of the active crystal 10 and impacts on a ~~deflecting~~ deflecting dichroic mirror 33 which reflects the beam 52 towards the interior of the cavity 72 through a face 34. The beam 52, deflected by the dichroic mirror 33, then impacts on the first face 21 of a non linear crystal 20, exiting therefrom through a second face 22 to be reflected by the face 37 of a bottom mirror 36. Said mirror 30, 33, 36 define an optical axis of the cavity 72, i.e. an optical axis 50 of propagation of the laser beam 52 at fundamental wavelength. Said laser beam 52 thus oscillates in the cavity 72 from the pumping mirror 31, through the dichroic mirror 33, to the bottom mirror 36, then again passing on the dichroic mirror 33, to the pumping mirror 31. During said oscillation, in the passage of the laser beam 52 to a frequency w through the non linear crystal 20, by second harmonic generation a

example dielectric coatings obtained by sputtering techniques. The choice of such coatings allows to obtain, for a complete pass in the cavity of the laser beam 52 with polarization *s*, a total loss of only 0.2%.

The device 71 comprises a structural base 45 made of copper or other metallic or ceramic material with good heat conduction characteristics, whereon are constructed the remaining elements of the device 71; the side of the structure 45 underlying the laser cavity 72 is realised in the manner of a well polished plane to allow an excellent heat exchange with an element with regulated temperature, such as a Peltier cell with active temperature control or a thermoregulated water exchanger.

The mirrors 30, 33 and 36 are mounted on respective supports 41, 42 and 44 which have good thermal contact with the structural base 45, so that the entire cavity 72 is a part of a same thermal circuit and temperature-stabilised: one thereby obtains a better mechanical stability and insensitivity to the misalignment caused by changes in external climatic conditions, as well as a marked frequency stability of the cavity.

Other desirable optical characteristics for the mirrors are:

- the pumping mirror 30 can have its reflecting face 31 treated with an appropriate layer that is antireflecting at the pumping wavelength (typically 800-808 nm or 879 nm) and antireflecting at one or more of the characteristic wavelengths of the laser crystal 10, where the system has to operate at a wavelength disadvantageous in terms of stimulated emission ~~cross-section~~ cross-section: if, for instance, the laser operates at 912 nm of fundamental wavelength, the pumping mirror 30 can be treated in such a way as to be antireflecting at 1064

overlapping between the laser mode and the pump beam 54; preferably, the length, together with other parameters of the resonator 72 can be chosen to allow the operation of the laser in the $TEM_{0,0}$ mode, with a beam at the diffraction limit, to maximise the efficiency of the ICSHG process.

In proximity to the pumping mirror 30, and intersecting the optical cavity axis 50 and the ~~directrix~~ direction of the pump beam 54, is the laser crystal 10, which can be obtained from an $Nd:GdVO_4$ crystal, cut according to the crystallographic axis *a* and oriented so that its crystallographic axis *c* coincides with the "*s*" polarization axis of the cavity 72. The laser crystal 10 houses in a mount 40 made of copper or other heat conducting material, which in turn is anchored to the structural base 45 to assure a good transmission of heat. Between the crystal 10 and the mount 40, adapting layers of Indium foil or other heat conductor materials form an efficient thermal interface.

The laser crystal 10 has the two faces 11 and 12 perpendicular to the optical axis 50 of the cavity 72, optically machined and provided with a dielectric coating with the following properties:

- the face 11 proximate to the pump mirror 30 is antireflecting at the fundamental infrared wavelength, with losses that should be lower than 0.1% and preferably in the order of 0.05%, and possibly with high transmission for the pump beam 54 which, traversing the face 11, enters the laser crystal 10 pumping it longitudinally.

- the face 12 opposite to the face 11 is antireflecting at the fundamental infrared wavelength, with losses that should be lower than 0.1% and preferably in the order of 0.05%.

## CLAIMS

1. A diode pumped laser apparatus for generating a visible power beam, of the type comprising:

- a linear ~~miniaturised~~ laser cavity (72), (—) discrete comprising at least the following optical elements (30,33,36,10,20):

- reflecting means (30;33;36) that are highly reflective at a fundamental wavelength of a laser beam (52) generated by said cavities (72), at least one of said reflecting means (30) being traversed by a pumping beam (54), at least one of said reflecting means (36) being reflecting at said fundamental wavelength and a second harmonic wavelength (51) with respect to said fundamental wavelength and at least one of said reflecting means (33) being highly transmissive at said second harmonic (51) of said fundamental wavelength;

- an active material (10) with linear polarized emission, ~~and with a gain configuration with small thermal aberration for the cavity mode,~~ said active material (10) being able to generate said laser beam (52) at a fundamental wavelength;

- a non linear crystal (20), inside said cavity (72);

characterised in that:

said non linear crystal (20) is able to generate a second harmonic (51) of said fundamental wavelength by critical type I phase matching and that

said cavity (72) is associated to thermostating means (45;41;42;43;44) for temperature locking said cavity (72) and its optical elements (30,33,36,10,20).

3 ~~2~~. An apparatus as claimed in one or more of the previous claims ~~1~~, characterised in that said cavity (72) and the optical means (30,33,36,10,20) which it comprises are arranged ~~selected~~ to minimise optical losses.

(whose length does not exceed ten times the sum of the lengths of the crystals included in the resonator,)

2. An apparatus as claimed in one or more of the preceding claims, characterised in that said active material (10) is arranged to keep the aberration losses at less than 2%.

[resonator is arranged to allow the operation of the laser in the $TEM_{0,0}$ mode.]

4 3. An apparatus as claimed in one of the previous claims, characterised in that said optical losses at said fundamental wavelength ~~are~~ at less than 2%.

5 4. An apparatus as claimed in one of the previous claims, characterised in that said optical losses at said fundamental wavelength due to thermal aberration ~~are~~ at less than 1%.

6 5. An apparatus as claimed in one of the claims from 1 through 5 4, characterised in that the active material (10) is a crystal of Nd:$GdVO_4$.

7 6. An apparatus as claimed in one of the claims from 1 through 5 4, characterised in that the active material (10) is a crystal of Nd:YLF.

8 7. An apparatus as claimed in one of the claims from 1 through 5 4, characterised in that the active material (10) is a crystal of Nd:YVO4.

9 8. An apparatus as claimed in one of the claims from 6 5 through 8 7, characterised in that the non linear crystal is LBO.

10 9. An apparatus as claimed in one of the claims from 6 5 through 8 7, characterised in that the non linear crystal is YCOB or GdCOB.

11 10. An apparatus as claimed in one of the previous claims, characterised in that said ~~visible beam (51) is a beam at the limit of diffraction, or $TEM_{0,0}$.~~

12 11. An apparatus as claimed in one of the previous claims, characterised in that the pumping beam (54) is absorbed in two successive passes through the active material (10).

13 12. Apparatus as claimed in one of the previous claims, characterised in that said thermostating means (45;41;42;43;44) for temperature locking said cavity (72) and its optical elements comprise a mechanical structure (45;41;42;43;44) associated to said cavity (72)

<said cavity (72) and said optical means (30,33,36,10,20) are arranged to keep>

14 ~~13~~. Apparatus as claimed in claim 13 ~~12~~, characterised in that said mechanical structure comprise a structural base (45), and elements for supporting the optics (41;42;43;44).

15 ~~14~~. Apparatus as claimed in claim 13 ~~12~~ or 14 ~~13~~, characterised in that said structural base (45) and elements supporting the optics (41;42;43;44) are made of copper or other heat conducting material and associated in thermal contact with each other.

16 ~~15~~. An apparatus as claimed in one of the claims from 13 ~~12~~ through 15 ~~14~~, characterised in that the temperature of the structural base (45) is regulated by means of an active system.

17 ~~16~~. An apparatus as claimed in one of the claims from 13 ~~12~~ through 16 ~~15~~ characterised in that said mechanical structure (45;41;42;43;44) has the shape of a container, containing said cavity (72) in sealed way.

18 ~~17~~. Apparatus as claimed in one of the previous claims, characterised in that said thermostating means (45;41;42;43;44) comprise an additional autonomous heat-regulating device to stabilise the temperature of the non linear crystal (20) in autonomous and more precise way than the other elements of the cavity.

19 ~~18~~. Apparatus as claimed in at least one of the previous claims, characterised in that the reflecting means (30;33;36) are at least in part obtained by means of reflecting depositions on the laser crystal (10) and/or on the non linear crystal (20).

20 ~~19~~. A method for generating a visible laser beam ~~in~~ a laser cavity (72) of the type whereby a non linear crystal (20) is inserted into said laser cavity (72) to obtain said visible laser beam (51) through a second harmonic generation operation, characterised in that it comprises the following operations:

<< in an apparatus according to one or more of the preceding claims, said apparatus comprising >>

- selecting a non linear crystal (20) cut for critical type I phase matching;

- aligning said non linear crystal (20) at a temperature predetermined by the thermostating means (45) associated to said cavity (72) obtaining the phase matching condition

- optimising the conversion into second harmonic with additional small temperature adjustments around the predetermined value.

21 ~~20~~. Method as claimed in claim ~~20~~ 19, characterised in that the temperature regulation operation occurs in negative feedback, detecting the signal of a sensor positioned in proximity to the non linear crystal.

22 ~~21~~. A method as claimed in claim ~~20~~ 19 or ~~21~~ 20, characterised in that it further comprises the operations of:

- reducing the walk-off of the fundamental laser beam (52) operating on the dimension of the cavity mode inside the non linear crystal (20), in order to contain the walk-off angle inside the divergence of the beam;

- selecting the length of the non linear crystal as a function of the desired focussing.